FIG. 1

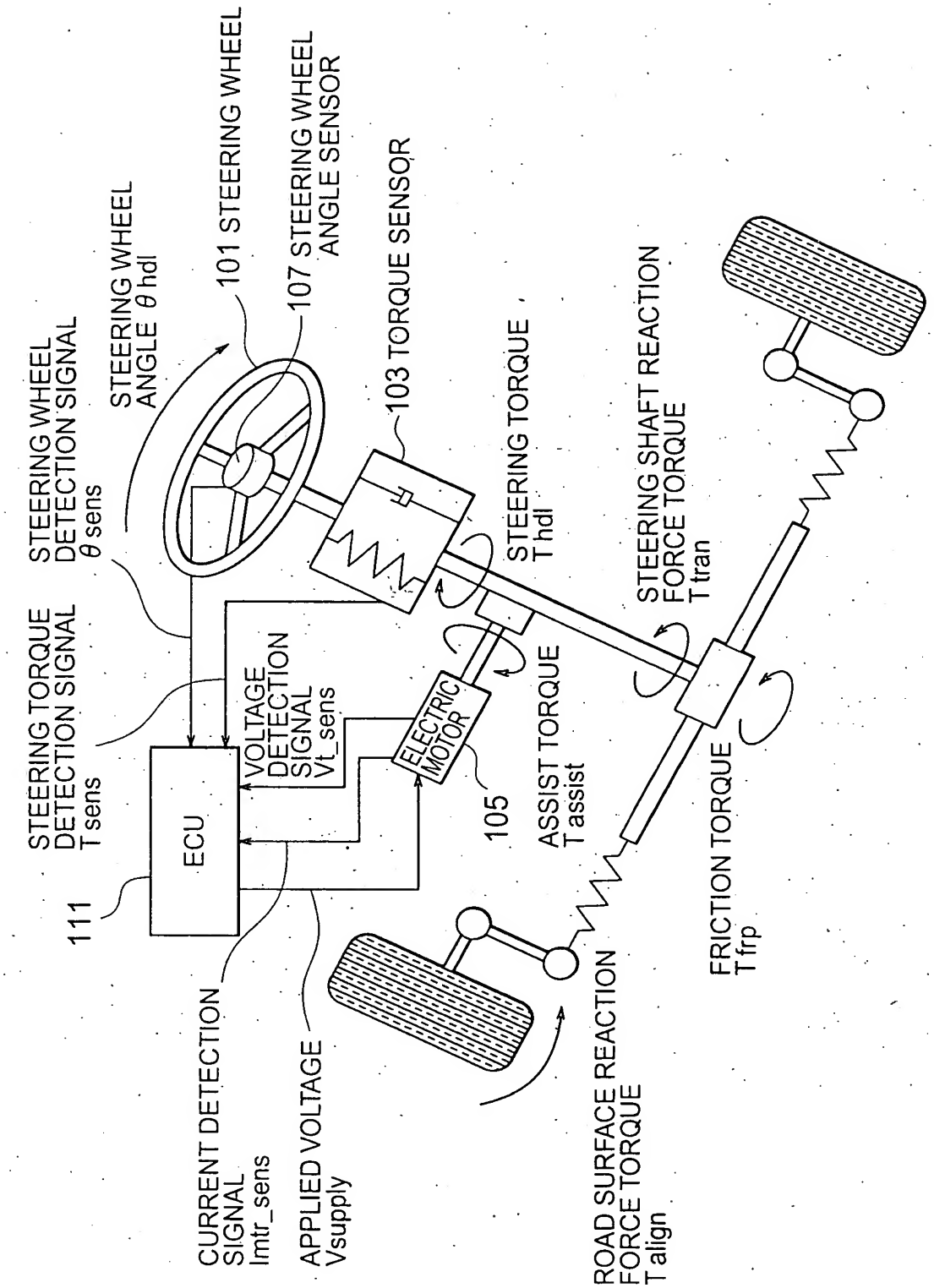
101 STEERING WHEEL
107 STEERING WHEEL ANGLE SENSOR
103 TORQUE SENSOR
STEERING WHEEL ANGLE θ hdl
STEERING WHEEL DETECTION SIGNAL θ sens
STEERING TORQUE DETECTION SIGNAL T sens
STEERING TORQUE T hdl
STEERING SHAFT REACTION FORCE TORQUE T tran
VOLTAGE DETECTION SIGNAL Vt_sens
ELECTRIC MOTOR
105
ASSIST TORQUE T assist
111
ECU
CURRENT DETECTION SIGNAL Imtr_sens
APPLIED VOLTAGE Vsupply
ROAD SURFACE REACTION FORCE TORQUE T align
FRICTION TORQUE T frp

FIG. 2

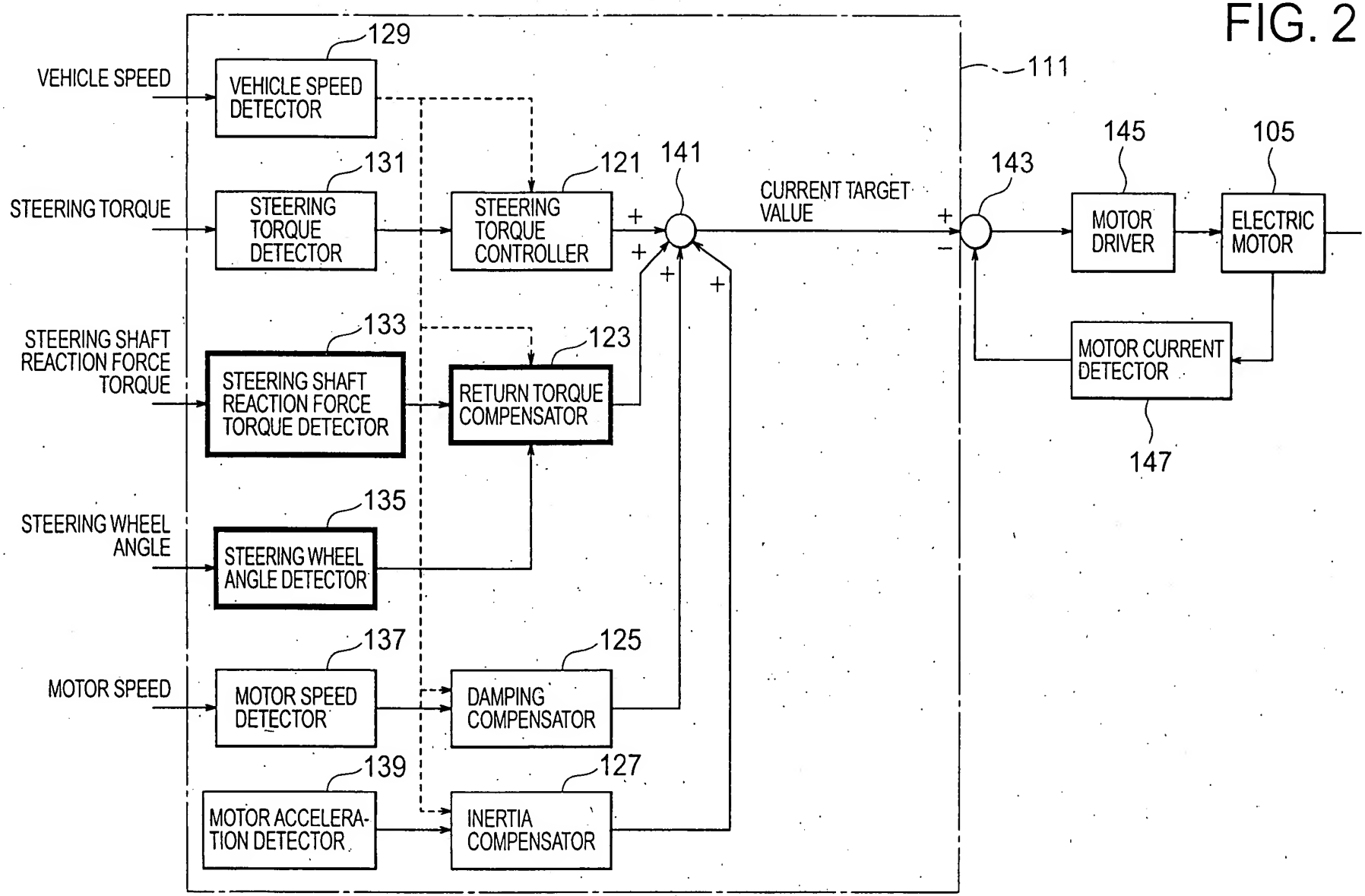
VEHICLE SPEED
129
VEHICLE SPEED DETECTOR
111
STEERING TORQUE
131
STEERING TORQUE DETECTOR
121
STEERING TORQUE CONTROLLER
141
CURRENT TARGET VALUE
143
145
MOTOR DRIVER
105
ELECTRIC MOTOR
STEERING SHAFT REACTION FORCE TORQUE
133
STEERING SHAFT REACTION FORCE TORQUE DETECTOR
123
RETURN TORQUE COMPENSATOR
MOTOR CURRENT DETECTOR
147
STEERING WHEEL ANGLE
135
STEERING WHEEL ANGLE DETECTOR
MOTOR SPEED
137
MOTOR SPEED DETECTOR
125
DAMPING COMPENSATOR
139
MOTOR ACCELERATION DETECTOR
127
INERTIA COMPENSATOR

FIG. 3

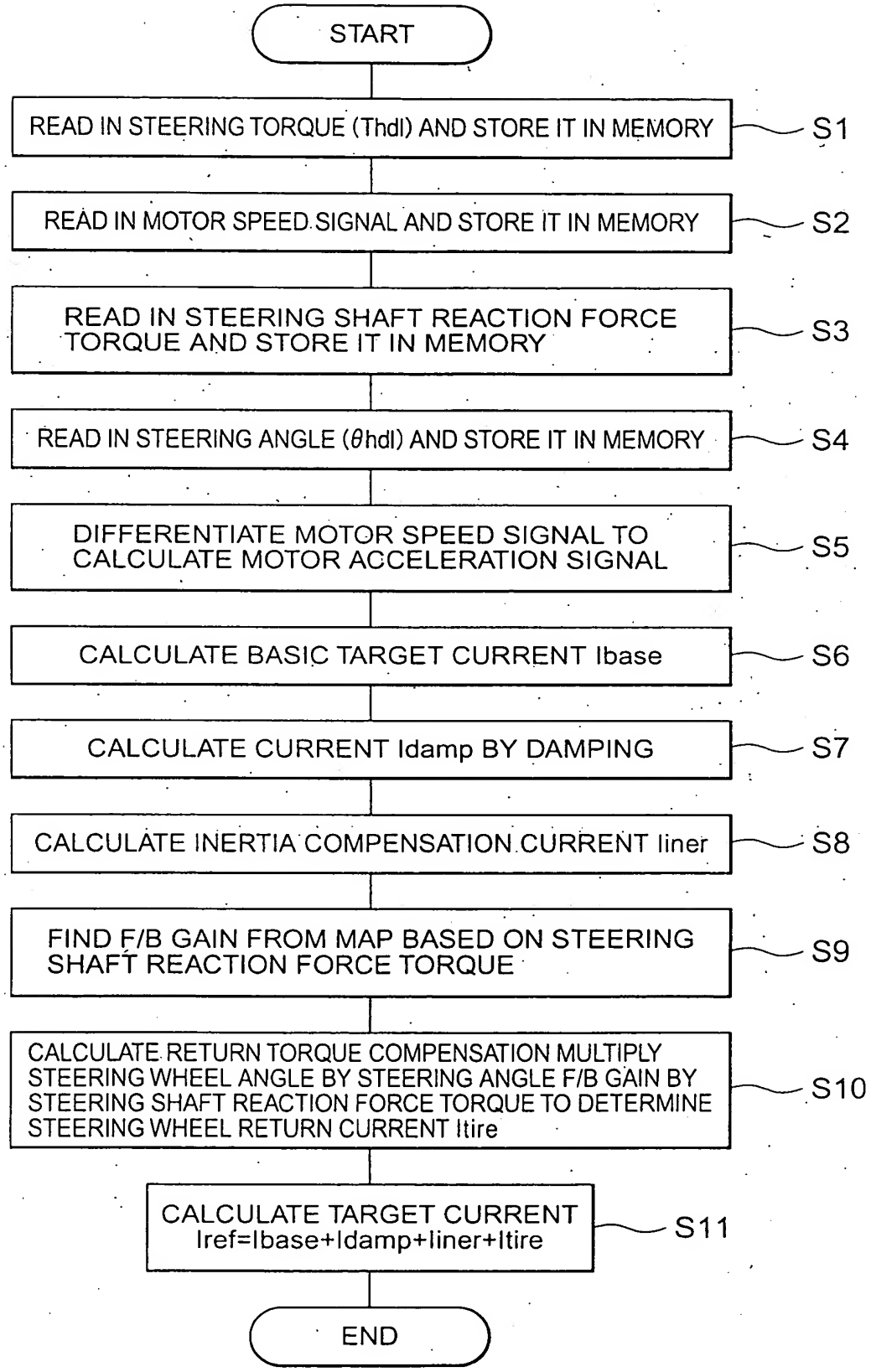
START
READ IN STEERING TORQUE (Thdl) AND STORE IT IN MEMORY
S1
READ IN MOTOR SPEED SIGNAL AND STORE IT IN MEMORY
S2
READ IN STEERING SHAFT REACTION FORCE TORQUE AND STORE IT IN MEMORY
S3
READ IN STEERING ANGLE (θhdl) AND STORE IT IN MEMORY
S4
DIFFERENTIATE MOTOR SPEED SIGNAL TO CALCULATE MOTOR ACCELERATION SIGNAL
S5
CALCULATE BASIC TARGET CURRENT Ibase
S6
CALCULATE CURRENT Idamp BY DAMPING
S7
CALCULATE INERTIA COMPENSATION CURRENT Iiner
S8
FIND F/B GAIN FROM MAP BASED ON STEERING SHAFT REACTION FORCE TORQUE
S9
CALCULATE RETURN TORQUE COMPENSATION MULTIPLY STEERING WHEEL ANGLE BY STEERING ANGLE F/B GAIN BY STEERING SHAFT REACTION FORCE TORQUE TO DETERMINE STEERING WHEEL RETURN CURRENT Itire
S10
CALCULATE TARGET CURRENT Iref=Ibase+Idamp+Iiner+Itire
S11
END

FIG. 4

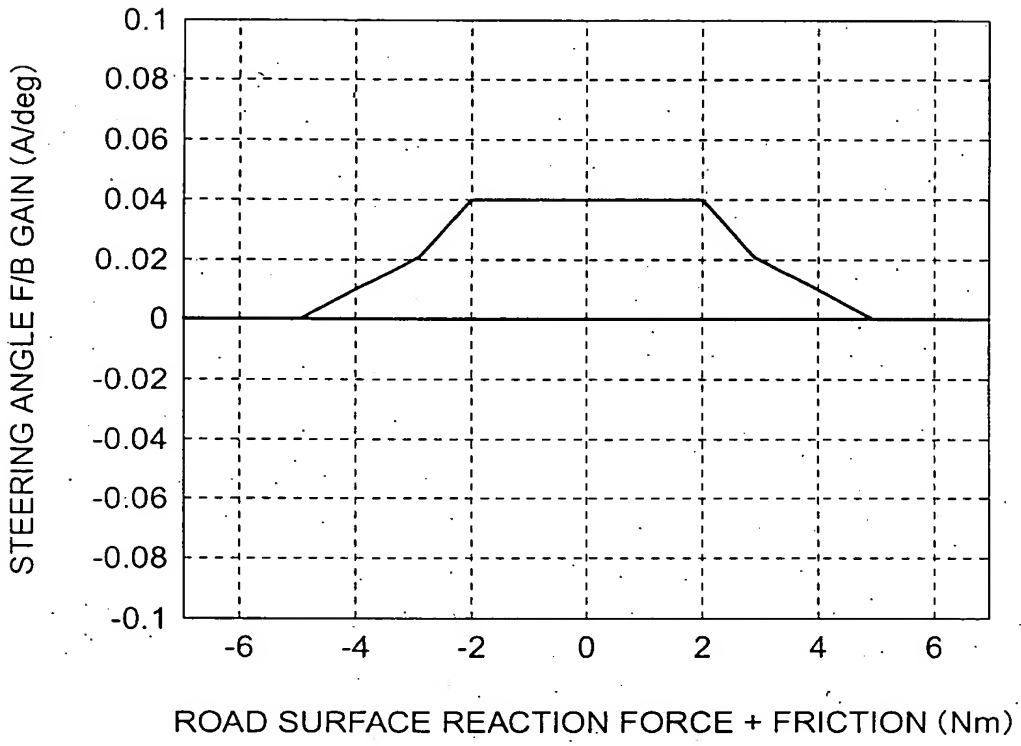
0.1
0.08
0.06
0.04
0..02
0
-0.02
-0.04
-0.06
-0.08
-0.1
STEERING ANGLE F/B GAIN (A/deg)
-6
-4
-2
0
2
4
6
ROAD SURFACE REACTION FORCE + FRICTION (Nm)

FIG. 5A

CORRECTED STEERING WHEEL ANGLE F/B COMPENSATION

(PRESENT INVENTION)

FIG. 5B

SIMPLE STEERING WHEEL ANGLE F/B COMPENSATION

(CONVENTIONAL METHOD)

RELATIONSHIP BETWEEN STEERING WHEEL ANGLE AND STEERING SHAFT REACTION FORCE TORQUE

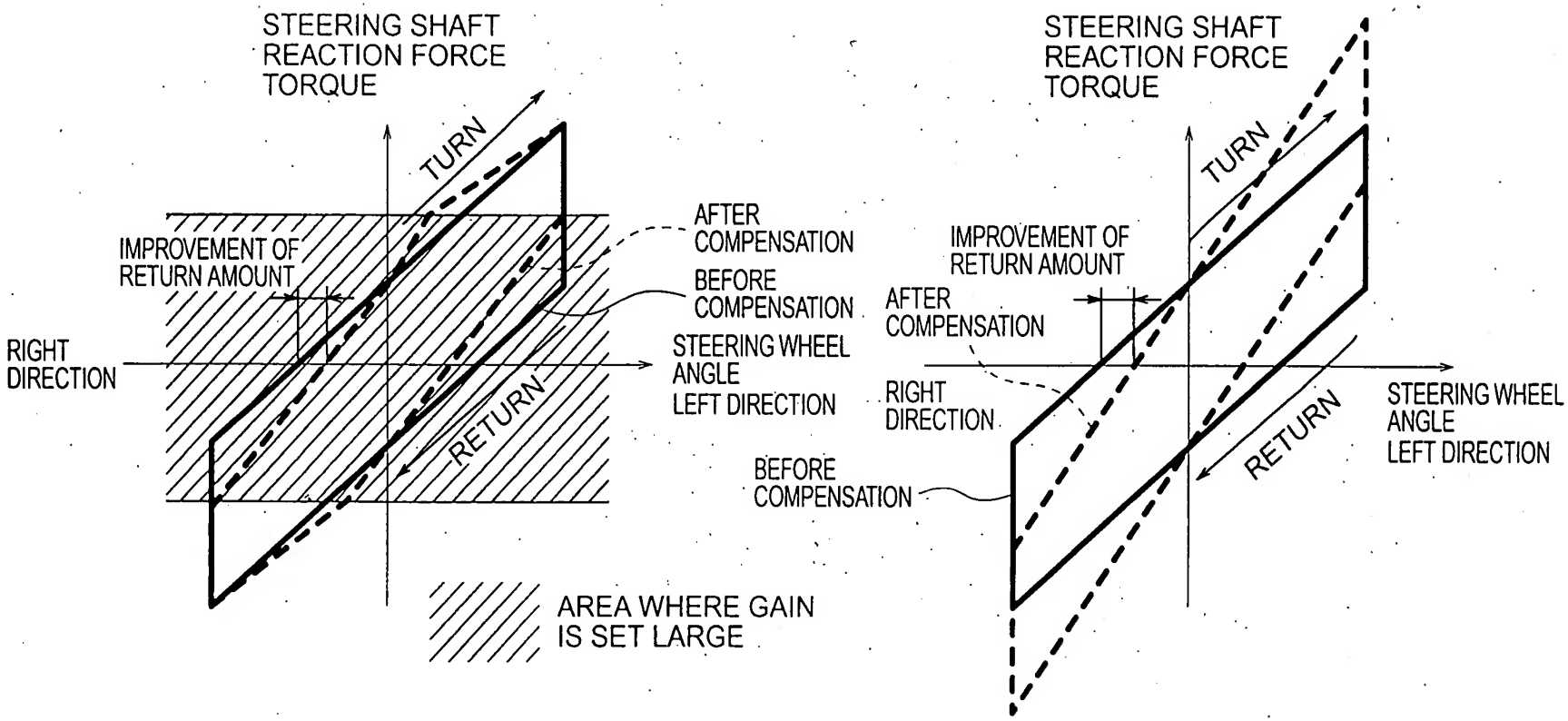

FIG. 6A

CORRECTED STEERING WHEEL ANGLE F/B COMPENSATION

(PRESENT INVENTION)

FIG. 6B

SIMPLE STEERING WHEEL ANGLE F/B COMPENSATION

(CONVENTIONAL METHOD)

____ RELATIONSHIP BETWEEN STEERING WHEEL ANGLE AND STEERING SHAFT REACTION FORCE TORQUE (SLIPPERY ROAD SURFACE) ____

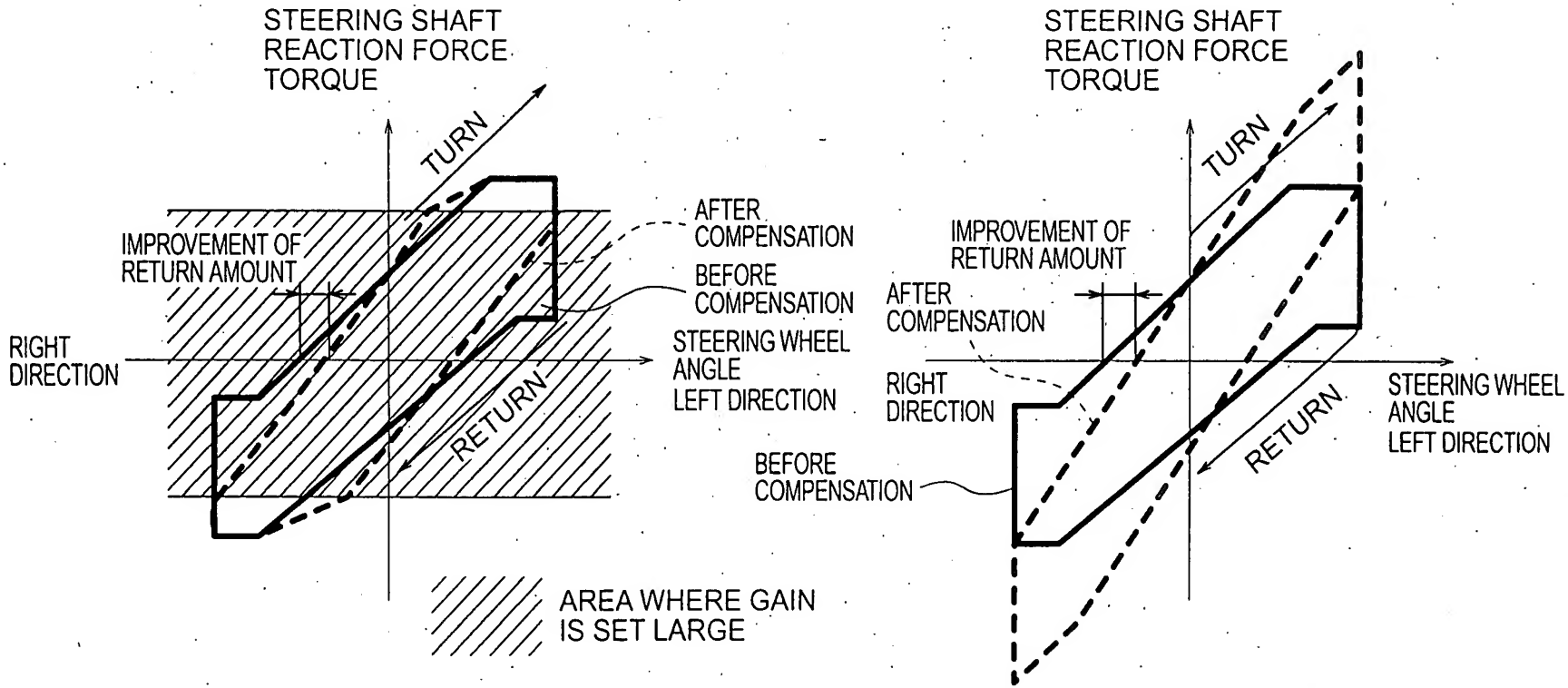

FIG. 7

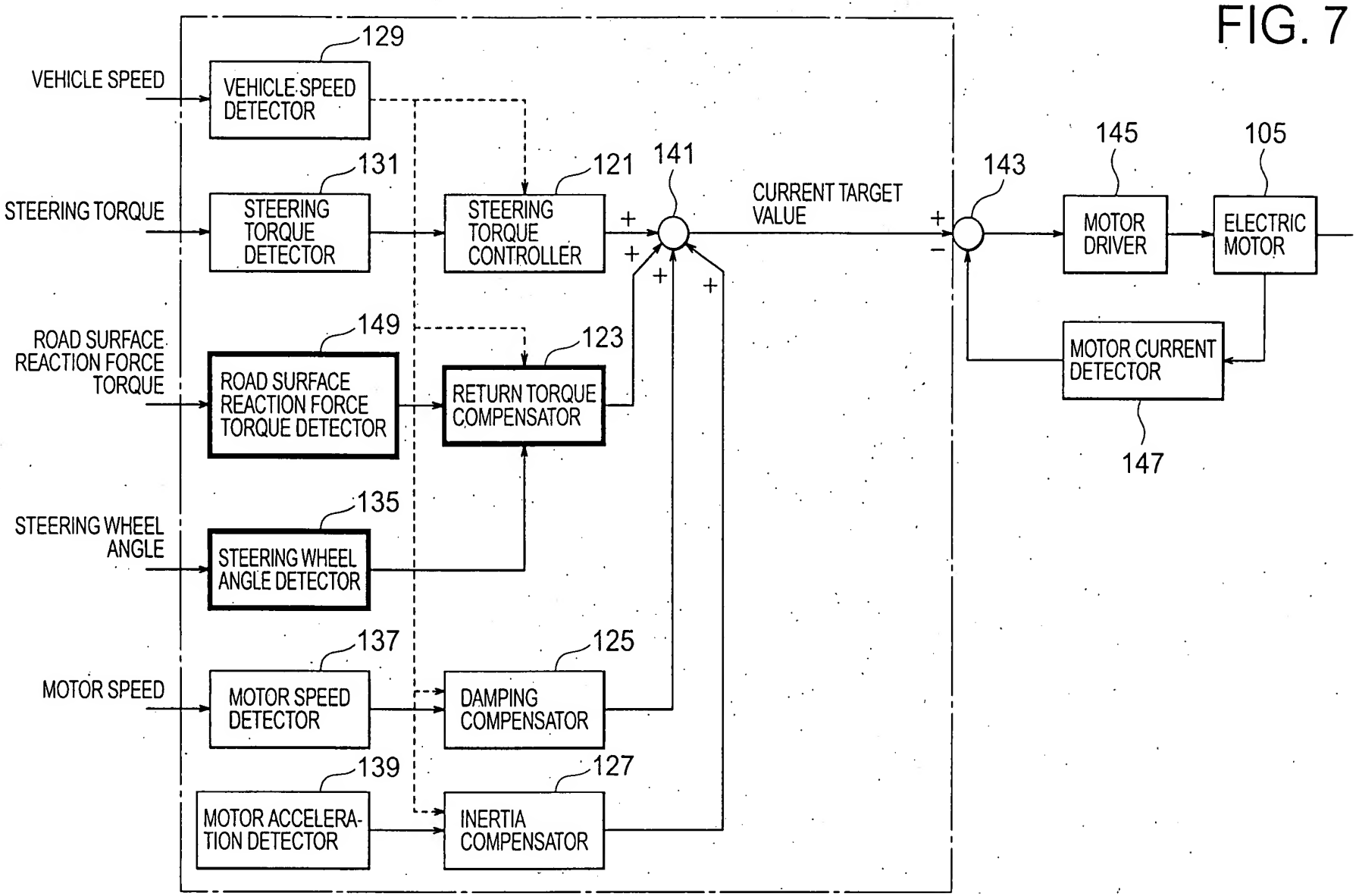
VEHICLE SPEED
129
VEHICLE SPEED DETECTOR
STEERING TORQUE
131
STEERING TORQUE DETECTOR
121
STEERING TORQUE CONTROLLER
141
CURRENT TARGET VALUE
143
145
MOTOR DRIVER
105
ELECTRIC MOTOR
ROAD SURFACE REACTION FORCE TORQUE
149
ROAD SURFACE REACTION FORCE TORQUE DETECTOR
123
RETURN TORQUE COMPENSATOR
MOTOR CURRENT DETECTOR
147
STEERING WHEEL ANGLE
135
STEERING WHEEL ANGLE DETECTOR
MOTOR SPEED
137
MOTOR SPEED DETECTOR
125
DAMPING COMPENSATOR
139
MOTOR ACCELERATION DETECTOR
127
INERTIA COMPENSATOR

FIG. 8

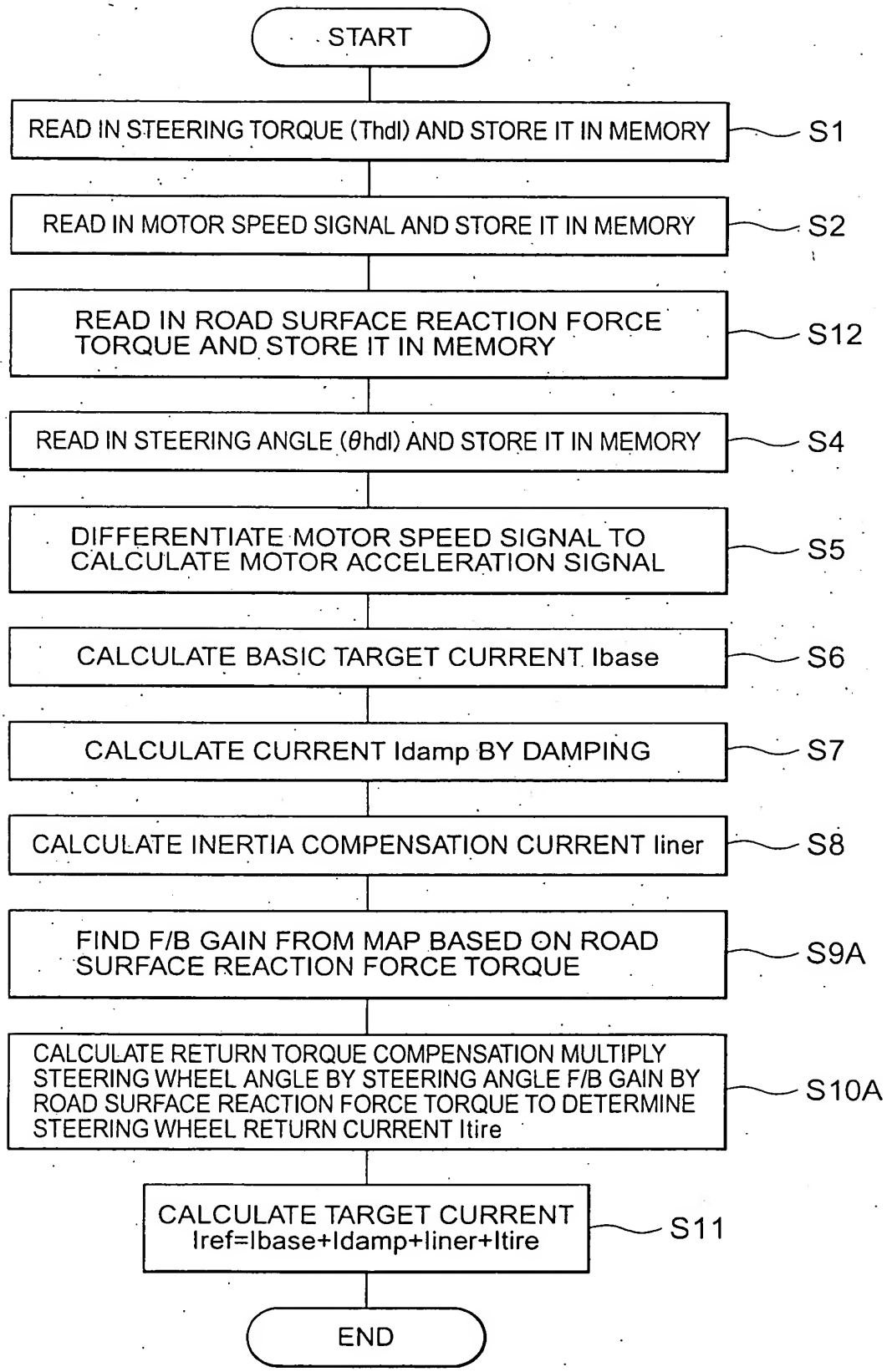
START
READ IN STEERING TORQUE (Thdl) AND STORE IT IN MEMORY
S1
READ IN MOTOR SPEED SIGNAL AND STORE IT IN MEMORY
S2
READ IN ROAD SURFACE REACTION FORCE TORQUE AND STORE IT IN MEMORY
S12
READ IN STEERING ANGLE (θhdl) AND STORE IT IN MEMORY
S4
DIFFERENTIATE MOTOR SPEED SIGNAL TO CALCULATE MOTOR ACCELERATION SIGNAL
S5
CALCULATE BASIC TARGET CURRENT Ibase
S6
CALCULATE CURRENT Idamp BY DAMPING
S7
CALCULATE INERTIA COMPENSATION CURRENT Iiner
S8
FIND F/B GAIN FROM MAP BASED ON ROAD SURFACE REACTION FORCE TORQUE
S9A
CALCULATE RETURN TORQUE COMPENSATION MULTIPLY STEERING WHEEL ANGLE BY STEERING ANGLE F/B GAIN BY ROAD SURFACE REACTION FORCE TORQUE TO DETERMINE STEERING WHEEL RETURN CURRENT Itire
S10A
CALCULATE TARGET CURRENT Iref=Ibase+Idamp+Iiner+Itire
S11
END

FIG. 9

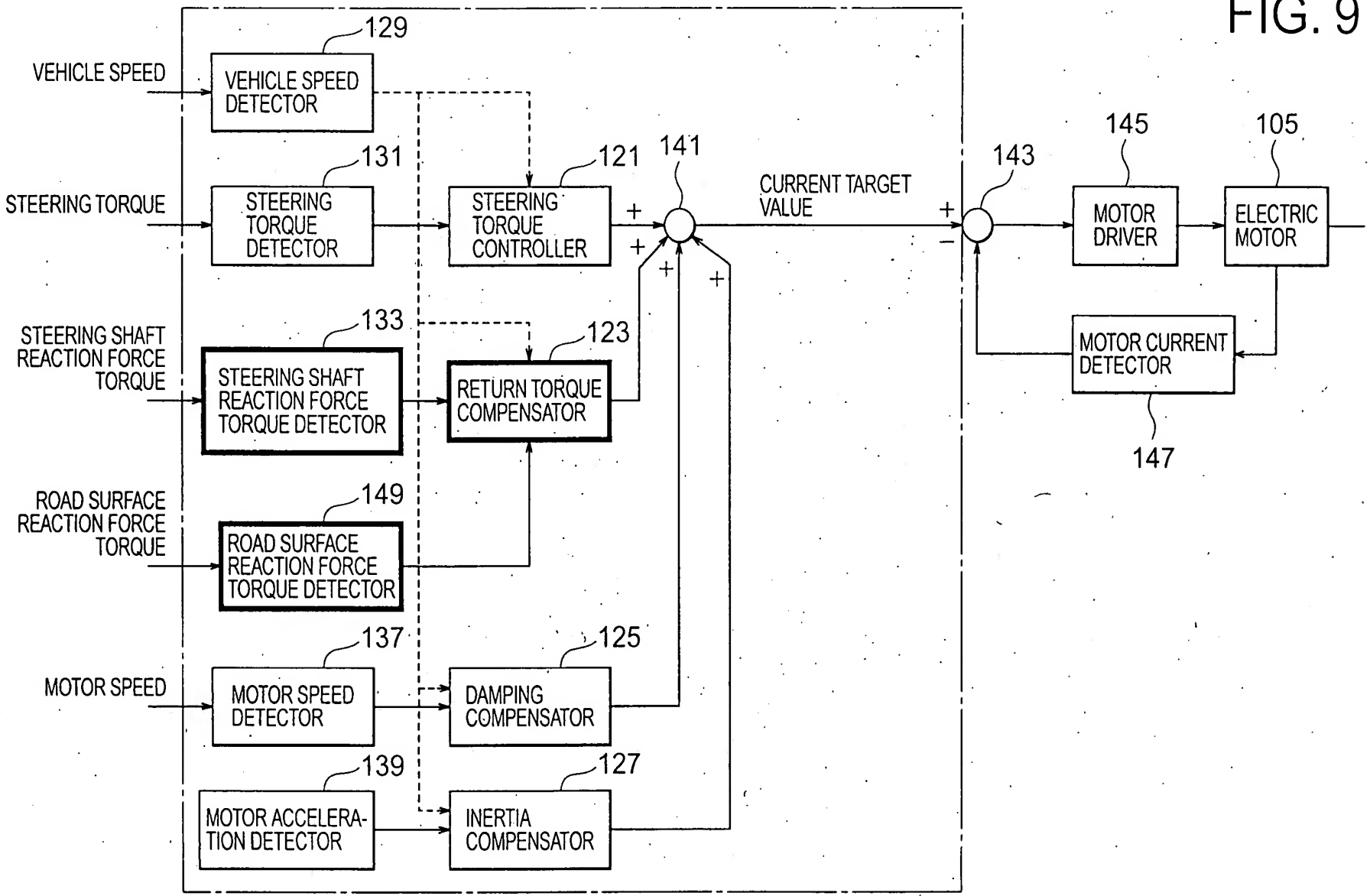
VEHICLE SPEED
129
VEHICLE SPEED DETECTOR
STEERING TORQUE
131
STEERING TORQUE DETECTOR
121
STEERING TORQUE CONTROLLER
141
CURRENT TARGET VALUE
143
145
MOTOR DRIVER
105
ELECTRIC MOTOR
STEERING SHAFT REACTION FORCE TORQUE
133
STEERING SHAFT REACTION FORCE TORQUE DETECTOR
123
RETURN TORQUE COMPENSATOR
MOTOR CURRENT DETECTOR
147
ROAD SURFACE REACTION FORCE TORQUE
149
ROAD SURFACE REACTION FORCE TORQUE DETECTOR
MOTOR SPEED
137
MOTOR SPEED DETECTOR
125
DAMPING COMPENSATOR
139
MOTOR ACCELERATION DETECTOR
127
INERTIA COMPENSATOR

FIG. 10

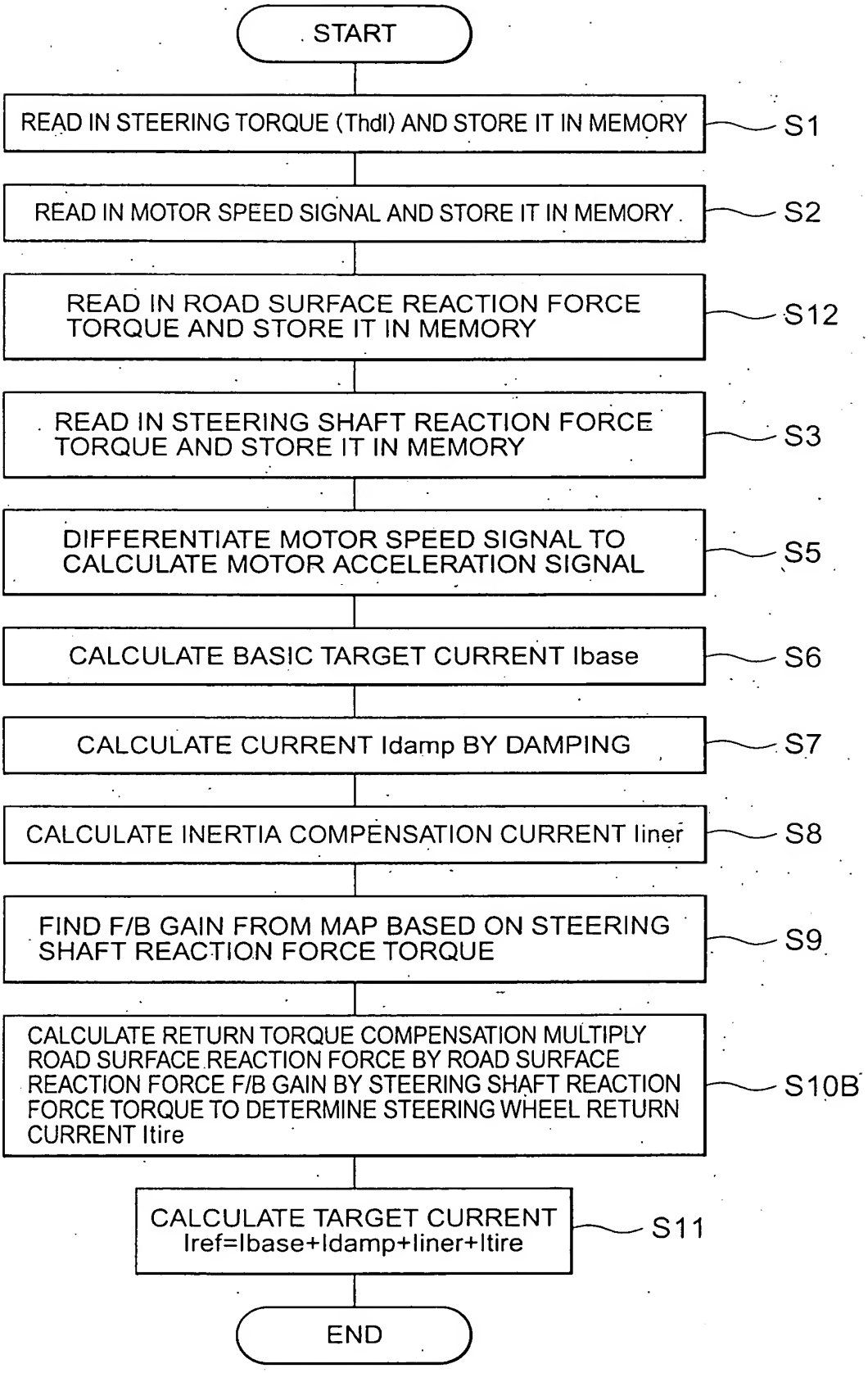
START
READ IN STEERING TORQUE (Thdl) AND STORE IT IN MEMORY
S1
READ IN MOTOR SPEED SIGNAL AND STORE IT IN MEMORY
S2
READ IN ROAD SURFACE REACTION FORCE TORQUE AND STORE IT IN MEMORY
S12
READ IN STEERING SHAFT REACTION FORCE TORQUE AND STORE IT IN MEMORY
S3
DIFFERENTIATE MOTOR SPEED SIGNAL TO CALCULATE MOTOR ACCELERATION SIGNAL
S5
CALCULATE BASIC TARGET CURRENT Ibase
S6
CALCULATE CURRENT Idamp BY DAMPING
S7
CALCULATE INERTIA COMPENSATION CURRENT Iiner
S8
FIND F/B GAIN FROM MAP BASED ON STEERING SHAFT REACTION FORCE TORQUE
S9
CALCULATE RETURN TORQUE COMPENSATION MULTIPLY ROAD SURFACE REACTION FORCE BY ROAD SURFACE REACTION FORCE F/B GAIN BY STEERING SHAFT REACTION FORCE TORQUE TO DETERMINE STEERING WHEEL RETURN CURRENT Itire
S10B
CALCULATE TARGET CURRENT Iref=Ibase+Idamp+Iiner+Itire
S11
END

FIG. 11

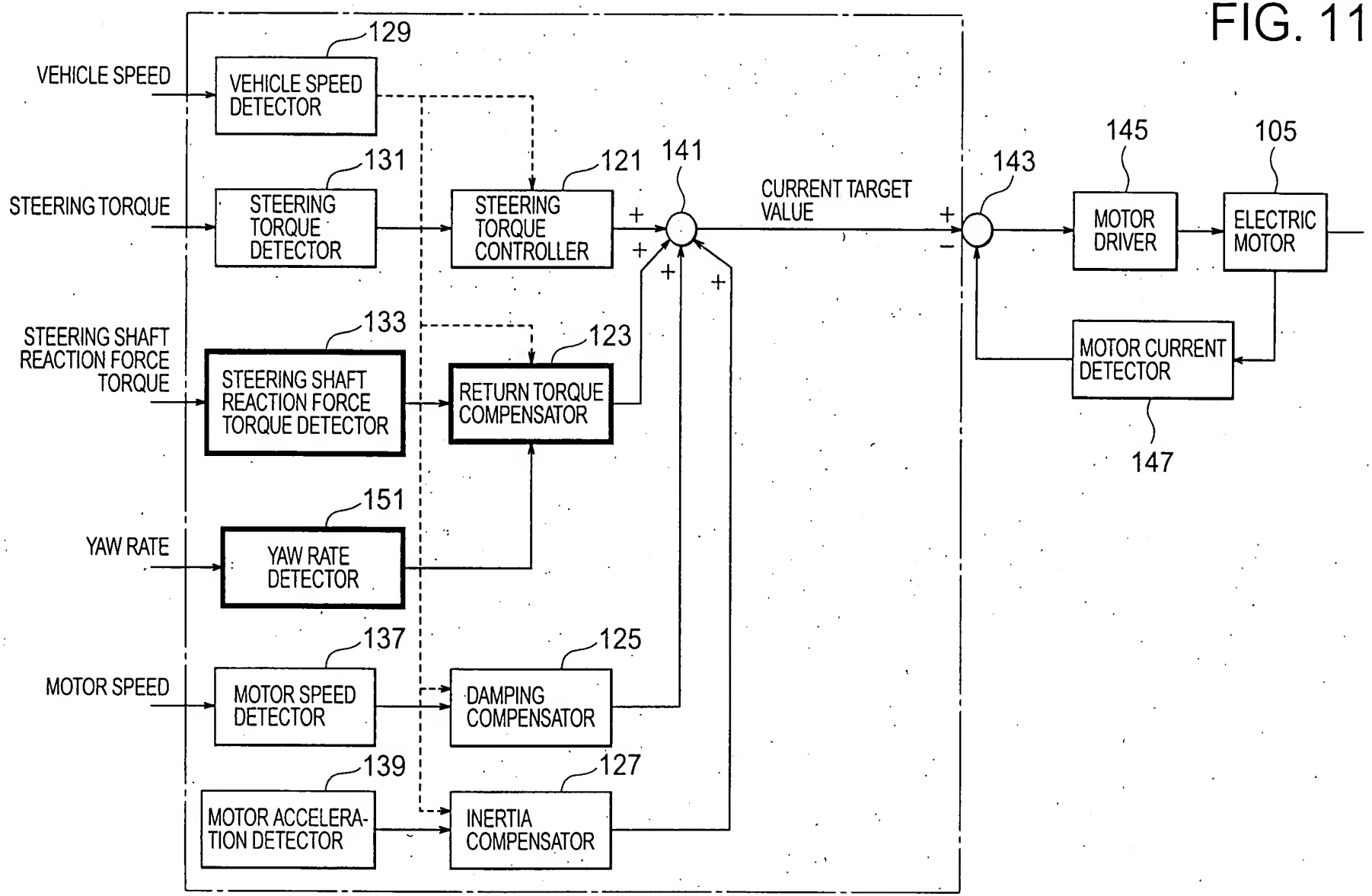
VEHICLE SPEED
129
VEHICLE SPEED DETECTOR
STEERING TORQUE
131
STEERING TORQUE DETECTOR
121
STEERING TORQUE CONTROLLER
141
CURRENT TARGET VALUE
143
145
MOTOR DRIVER
105
ELECTRIC MOTOR
STEERING SHAFT REACTION FORCE TORQUE
133
STEERING SHAFT REACTION FORCE TORQUE DETECTOR
123
RETURN TORQUE COMPENSATOR
MOTOR CURRENT DETECTOR
147
YAW RATE
151
YAW RATE DETECTOR
MOTOR SPEED
137
MOTOR SPEED DETECTOR
125
DAMPING COMPENSATOR
139
MOTOR ACCELERATION DETECTOR
127
INERTIA COMPENSATOR

FIG. 12

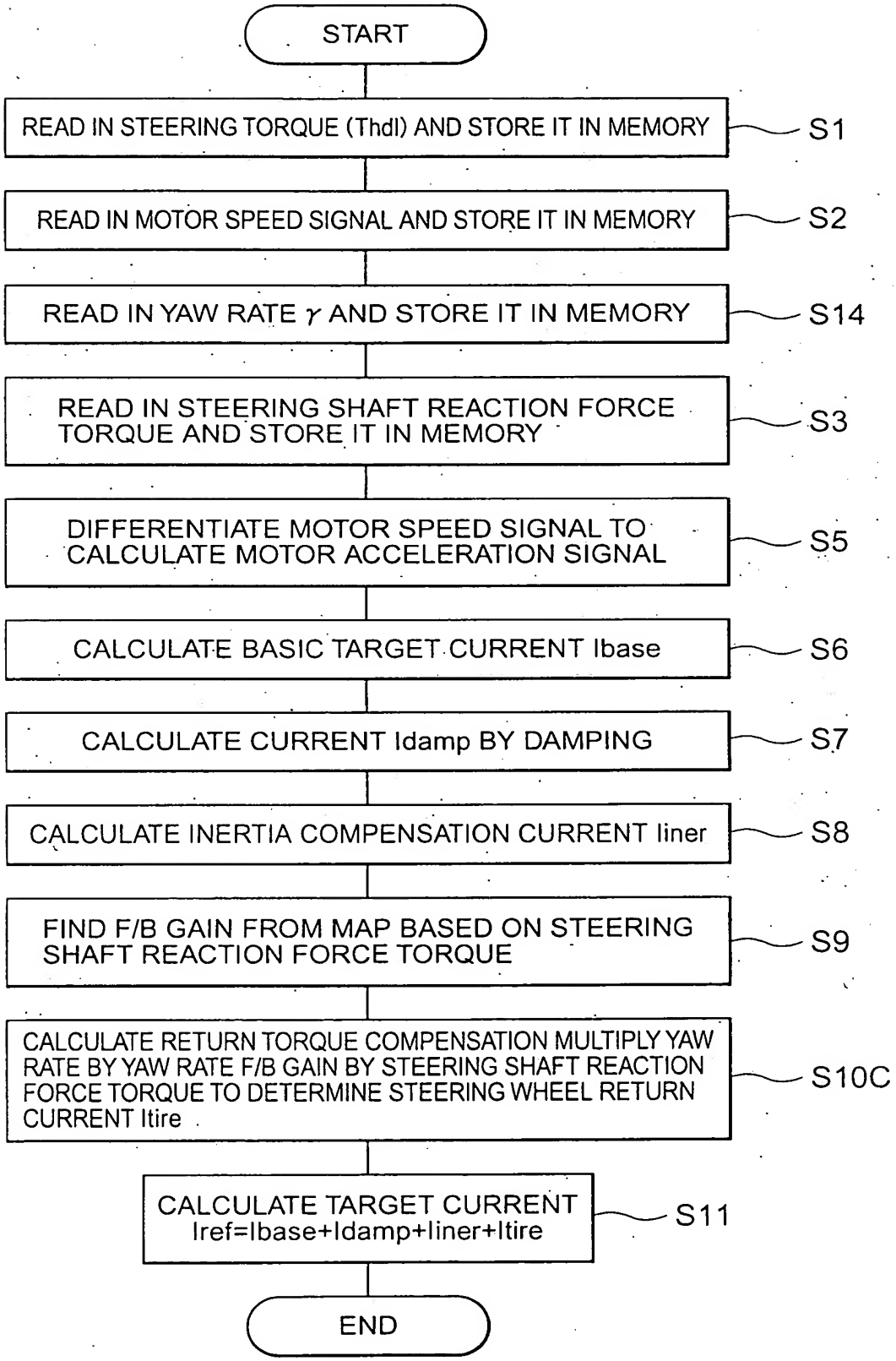
START
READ IN STEERING TORQUE (Thdl) AND STORE IT IN MEMORY
S1
READ IN MOTOR SPEED SIGNAL AND STORE IT IN MEMORY
S2
READ IN YAW RATE γ AND STORE IT IN MEMORY
S14
READ IN STEERING SHAFT REACTION FORCE TORQUE AND STORE IT IN MEMORY
S3
DIFFERENTIATE MOTOR SPEED SIGNAL TO CALCULATE MOTOR ACCELERATION SIGNAL
S5
CALCULATE BASIC TARGET CURRENT Ibase
S6
CALCULATE CURRENT Idamp BY DAMPING
S7
CALCULATE INERTIA COMPENSATION CURRENT Iiner
S8
FIND F/B GAIN FROM MAP BASED ON STEERING SHAFT REACTION FORCE TORQUE
S9
CALCULATE RETURN TORQUE COMPENSATION MULTIPLY YAW RATE BY YAW RATE F/B GAIN BY STEERING SHAFT REACTION FORCE TORQUE TO DETERMINE STEERING WHEEL RETURN CURRENT Itire
S10C
CALCULATE TARGET CURRENT Iref=Ibase+Idamp+Iiner+Itire
S11
END

FIG. 13

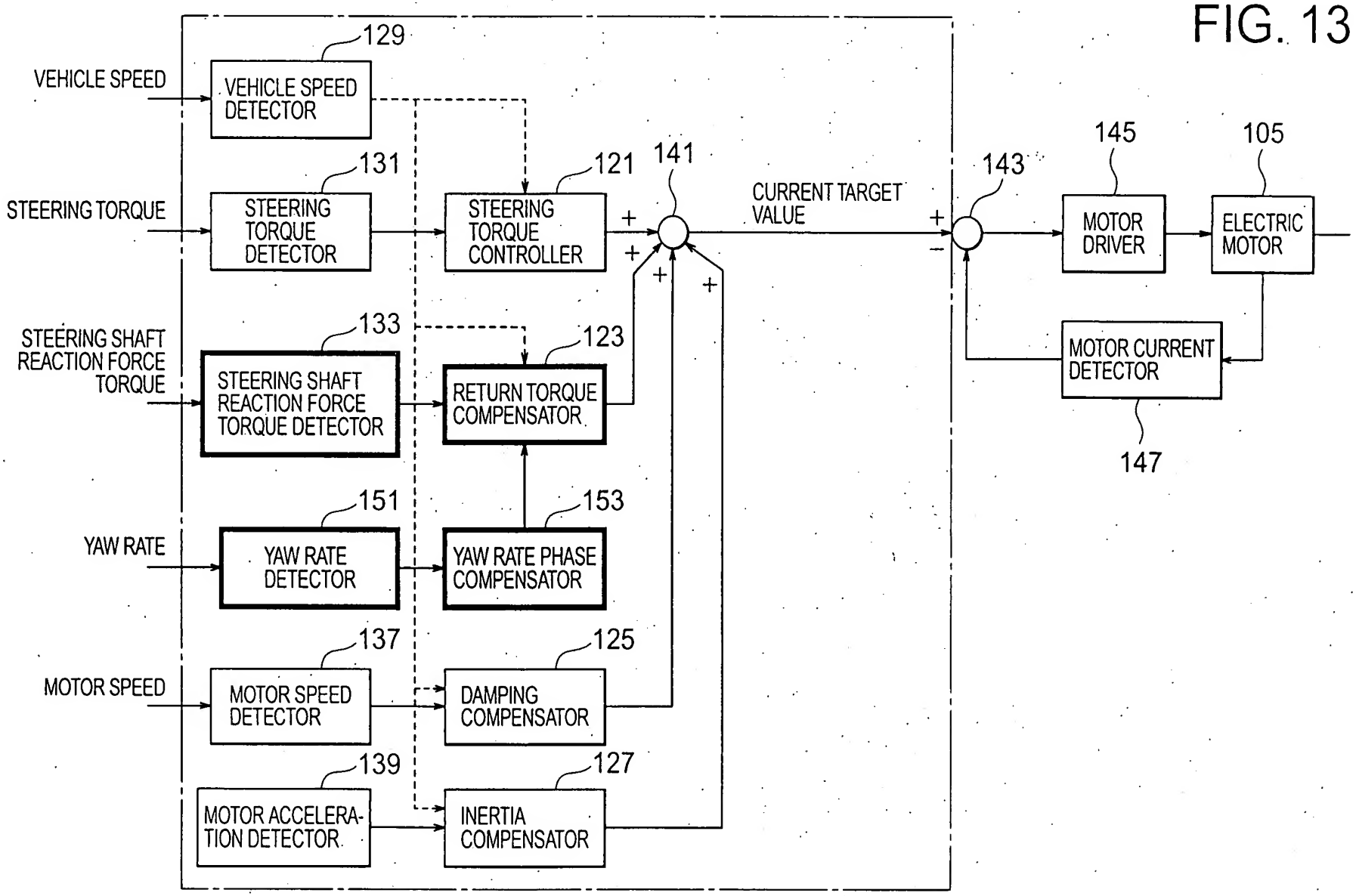
VEHICLE SPEED
129
VEHICLE SPEED DETECTOR
STEERING TORQUE
131
STEERING TORQUE DETECTOR
121
STEERING TORQUE CONTROLLER
141
CURRENT TARGET VALUE
143
145
MOTOR DRIVER
105
ELECTRIC MOTOR
STEERING SHAFT REACTION FORCE TORQUE
133
STEERING SHAFT REACTION FORCE TORQUE DETECTOR
123
RETURN TORQUE COMPENSATOR
MOTOR CURRENT DETECTOR
147
YAW RATE
151
YAW RATE DETECTOR
153
YAW RATE PHASE COMPENSATOR
MOTOR SPEED
137
MOTOR SPEED DETECTOR
125
DAMPING COMPENSATOR
139
MOTOR ACCELERATION DETECTOR
127
INERTIA COMPENSATOR

FIG. 14

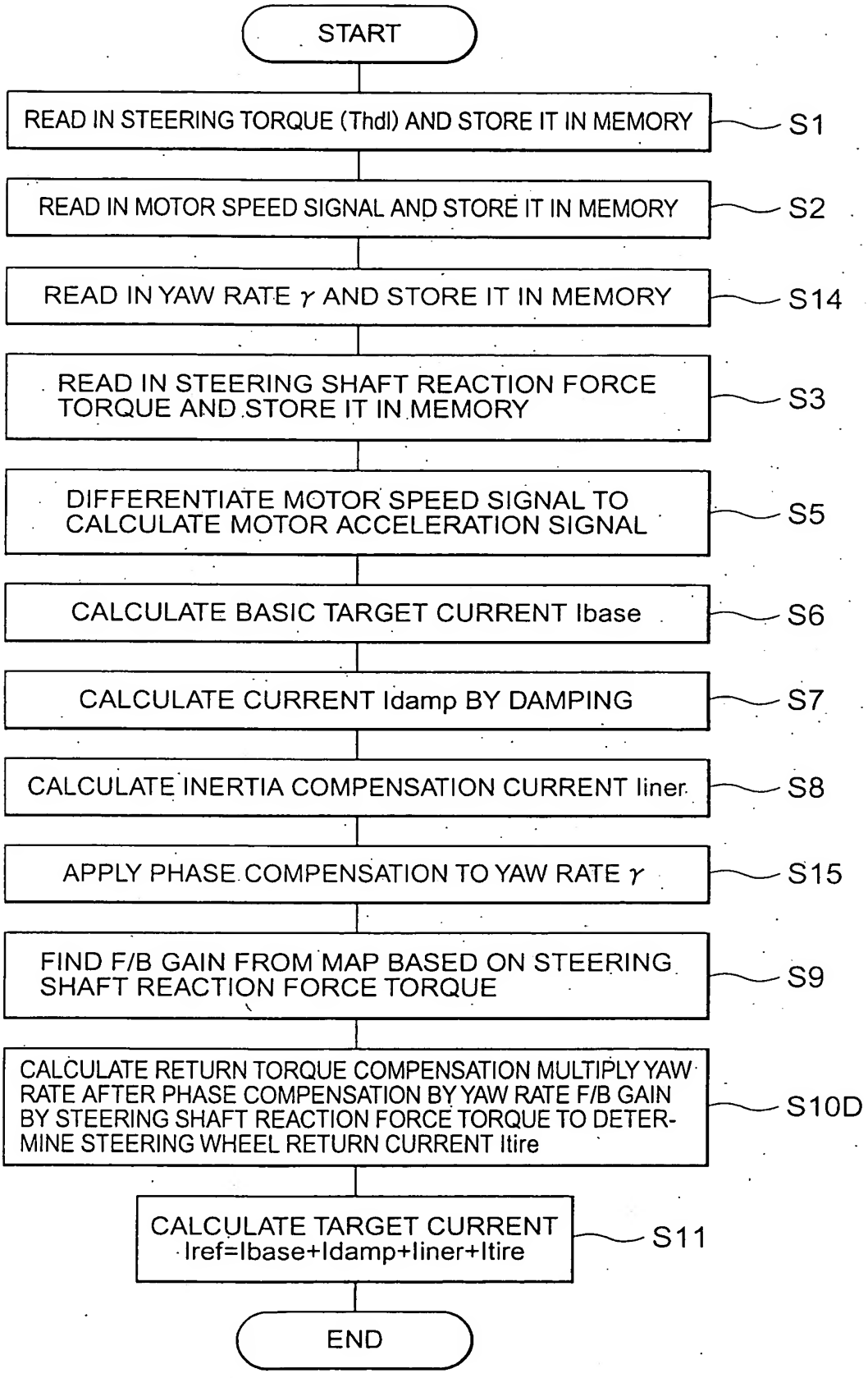
START
READ IN STEERING TORQUE (Thdl) AND STORE IT IN MEMORY
S1
READ IN MOTOR SPEED SIGNAL AND STORE IT IN MEMORY
S2
READ IN YAW RATE γ AND STORE IT IN MEMORY
S14
READ IN STEERING SHAFT REACTION FORCE TORQUE AND STORE IT IN MEMORY
S3
DIFFERENTIATE MOTOR SPEED SIGNAL TO CALCULATE MOTOR ACCELERATION SIGNAL
S5
CALCULATE BASIC TARGET CURRENT Ibase
S6
CALCULATE CURRENT Idamp BY DAMPING
S7
CALCULATE INERTIA COMPENSATION CURRENT Iiner
S8
APPLY PHASE COMPENSATION TO YAW RATE γ
S15
FIND F/B GAIN FROM MAP BASED ON STEERING SHAFT REACTION FORCE TORQUE
S9
CALCULATE RETURN TORQUE COMPENSATION MULTIPLY YAW RATE AFTER PHASE COMPENSATION BY YAW RATE F/B GAIN BY STEERING SHAFT REACTION FORCE TORQUE TO DETERMINE STEERING WHEEL RETURN CURRENT Itire
S10D
CALCULATE TARGET CURRENT Iref=Ibase+Idamp+Iiner+Itire
S11
END

FIG. 15

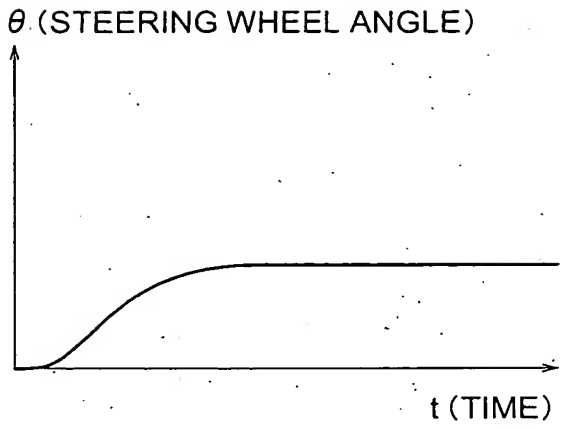

FIG. 16

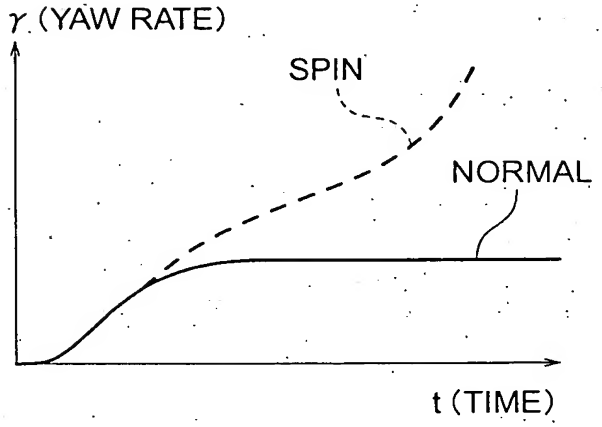

FIG. 17

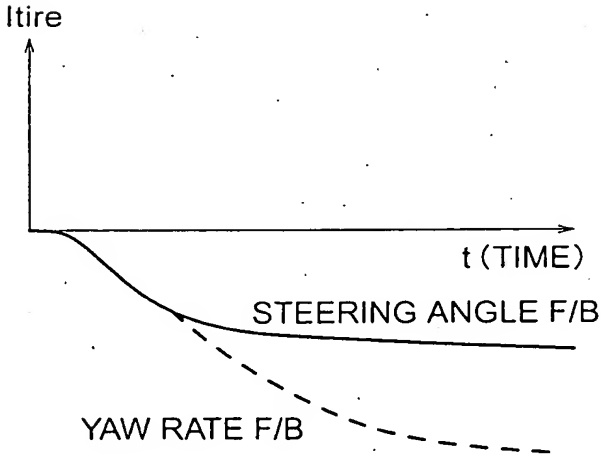

FIG. 18

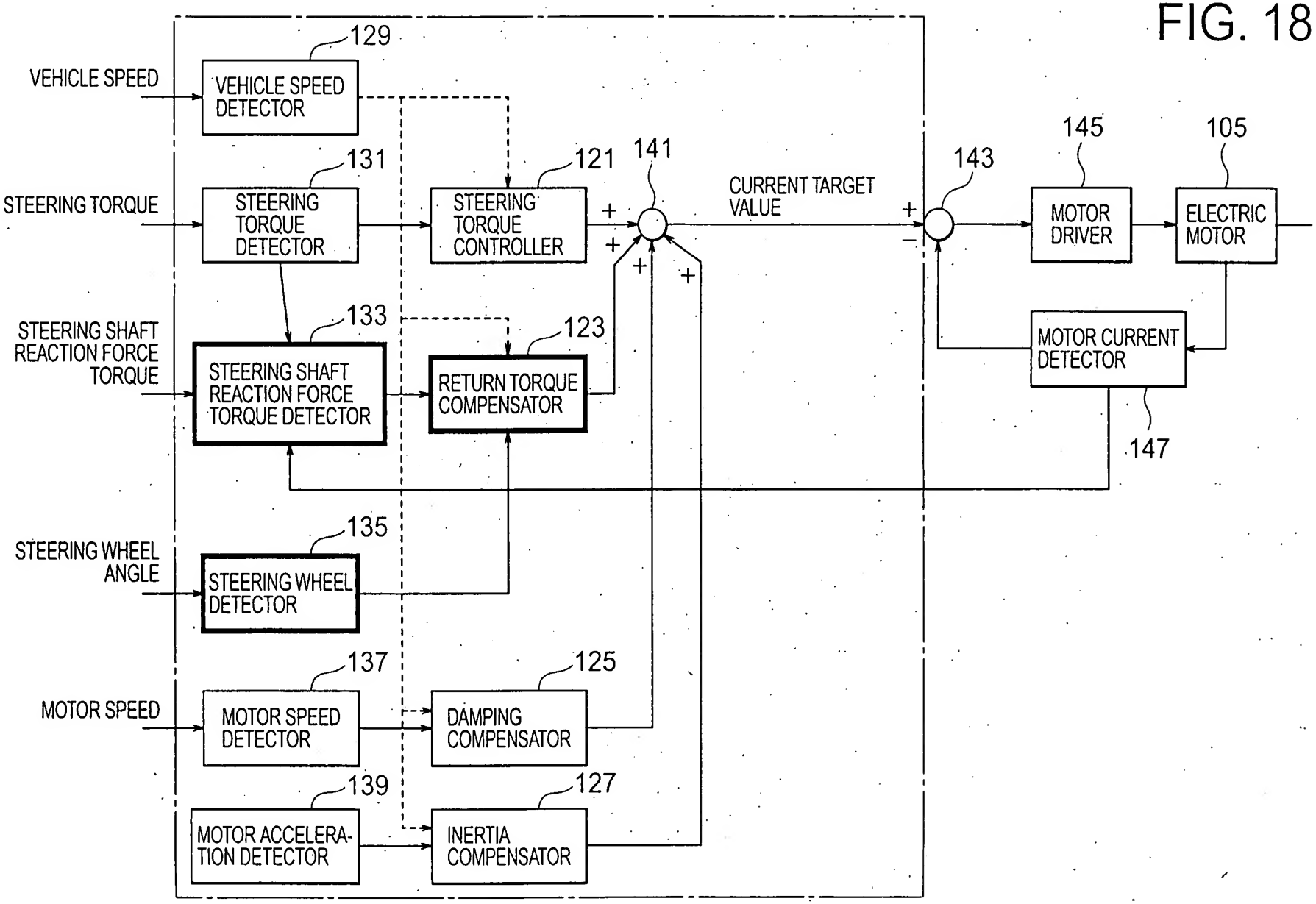
VEHICLE SPEED
129
VEHICLE SPEED DETECTOR
STEERING TORQUE
131
STEERING TORQUE DETECTOR
121
STEERING TORQUE CONTROLLER
141
CURRENT TARGET VALUE
143
145
MOTOR DRIVER
105
ELECTRIC MOTOR
STEERING SHAFT REACTION FORCE TORQUE
133
STEERING SHAFT REACTION FORCE TORQUE DETECTOR
123
RETURN TORQUE COMPENSATOR
MOTOR CURRENT DETECTOR
147
STEERING WHEEL ANGLE
135
STEERING WHEEL DETECTOR
MOTOR SPEED
137
MOTOR SPEED DETECTOR
125
DAMPING COMPENSATOR
139
MOTOR ACCELERATION DETECTOR
127
INERTIA COMPENSATOR

FIG. 19

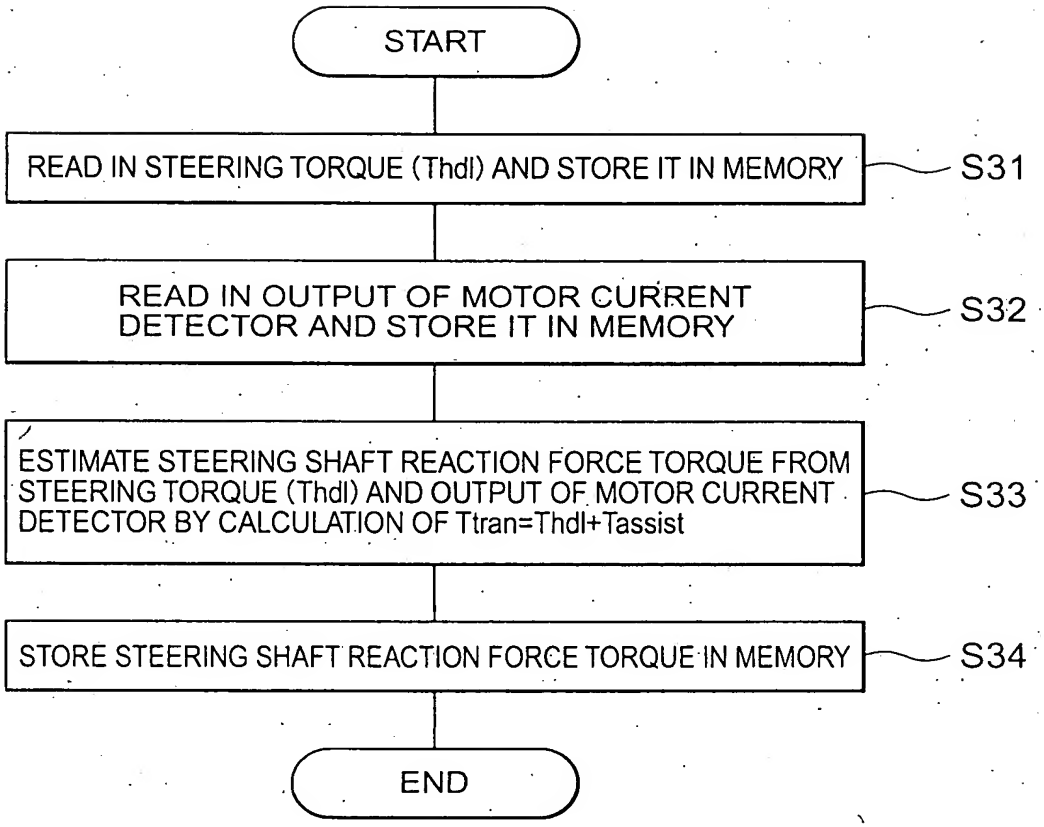
START
READ IN STEERING TORQUE (Thdl) AND STORE IT IN MEMORY
S31
READ IN OUTPUT OF MOTOR CURRENT DETECTOR AND STORE IT IN MEMORY
S32
ESTIMATE STEERING SHAFT REACTION FORCE TORQUE FROM STEERING TORQUE (Thdl) AND OUTPUT OF MOTOR CURRENT DETECTOR BY CALCULATION OF Ttran=Thdl+Tassist
S33
STORE STEERING SHAFT REACTION FORCE TORQUE IN MEMORY
S34
END

FIG. 20

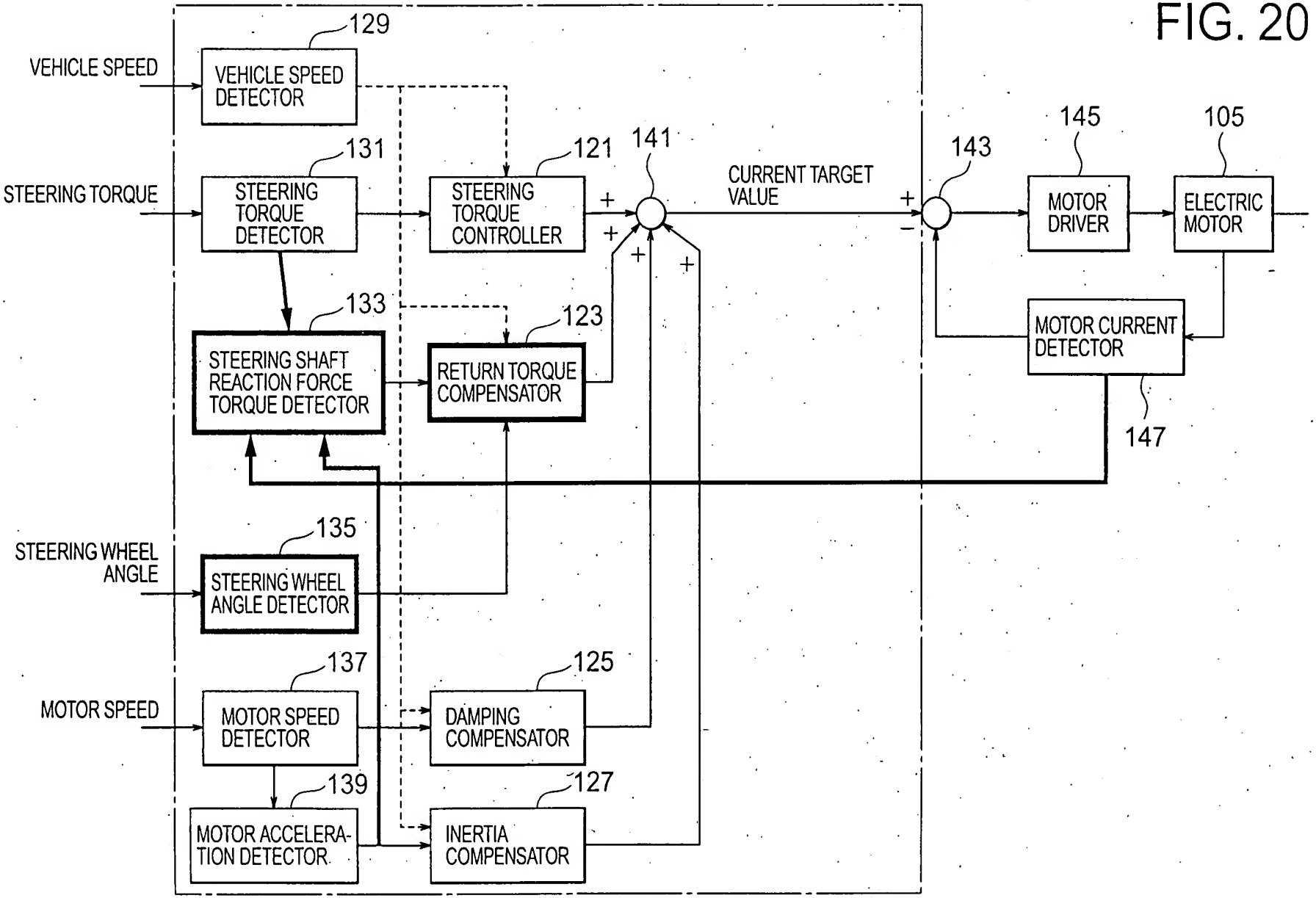
VEHICLE SPEED
129
VEHICLE SPEED DETECTOR
STEERING TORQUE
131
STEERING TORQUE DETECTOR
121
STEERING TORQUE CONTROLLER
141
CURRENT TARGET VALUE
143
145
MOTOR DRIVER
105
ELECTRIC MOTOR
133
STEERING SHAFT REACTION FORCE TORQUE DETECTOR
123
RETURN TORQUE COMPENSATOR
MOTOR CURRENT DETECTOR
147
STEERING WHEEL ANGLE
135
STEERING WHEEL ANGLE DETECTOR
MOTOR SPEED
137
MOTOR SPEED DETECTOR
125
DAMPING COMPENSATOR
139
MOTOR ACCELERATION DETECTOR
127
INERTIA COMPENSATOR

FIG. 21

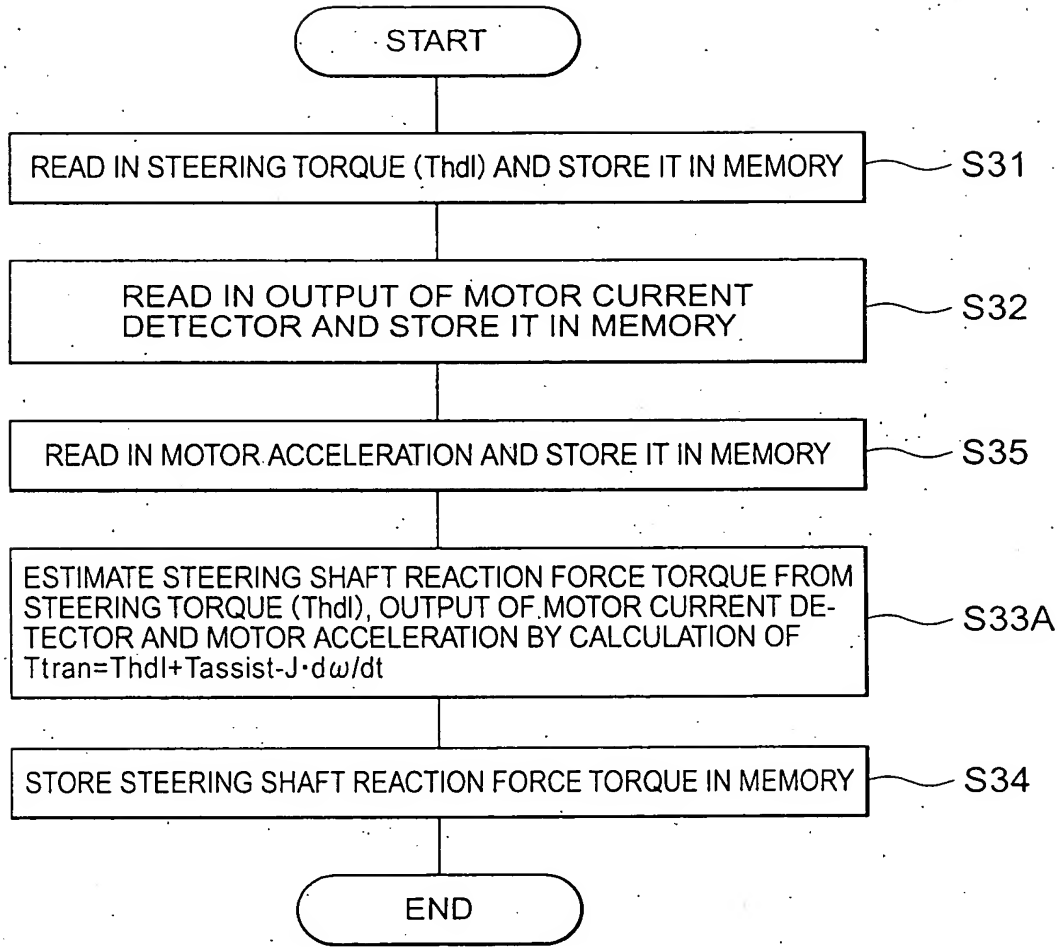
START
READ IN STEERING TORQUE (Thdl) AND STORE IT IN MEMORY
S31
READ IN OUTPUT OF MOTOR CURRENT DETECTOR AND STORE IT IN MEMORY
S32
READ IN MOTOR ACCELERATION AND STORE IT IN MEMORY
S35
ESTIMATE STEERING SHAFT REACTION FORCE TORQUE FROM STEERING TORQUE (Thdl), OUTPUT OF MOTOR CURRENT DETECTOR AND MOTOR ACCELERATION BY CALCULATION OF Ttran=Thdl+Tassist-J·dω/dt
S33A
STORE STEERING SHAFT REACTION FORCE TORQUE IN MEMORY
S34
END

FIG. 22

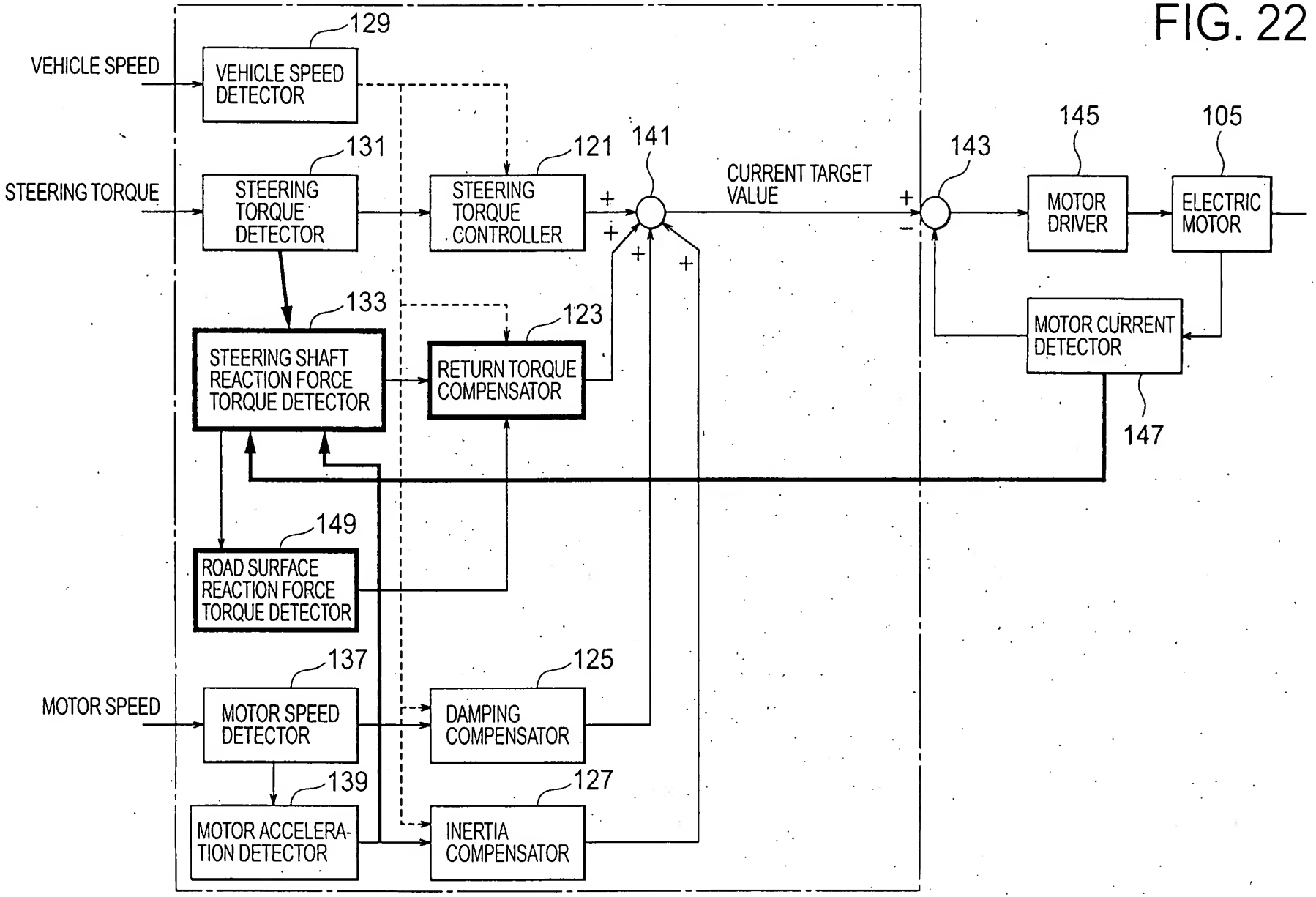
VEHICLE SPEED
129
VEHICLE SPEED DETECTOR
STEERING TORQUE
131
STEERING TORQUE DETECTOR
121
STEERING TORQUE CONTROLLER
141
CURRENT TARGET VALUE
143
145
MOTOR DRIVER
105
ELECTRIC MOTOR
133
STEERING SHAFT REACTION FORCE TORQUE DETECTOR
123
RETURN TORQUE COMPENSATOR
MOTOR CURRENT DETECTOR
147
149
ROAD SURFACE REACTION FORCE TORQUE DETECTOR
MOTOR SPEED
137
MOTOR SPEED DETECTOR
125
DAMPING COMPENSATOR
139
MOTOR ACCELERATION DETECTOR
127
INERTIA COMPENSATOR

FIG. 23

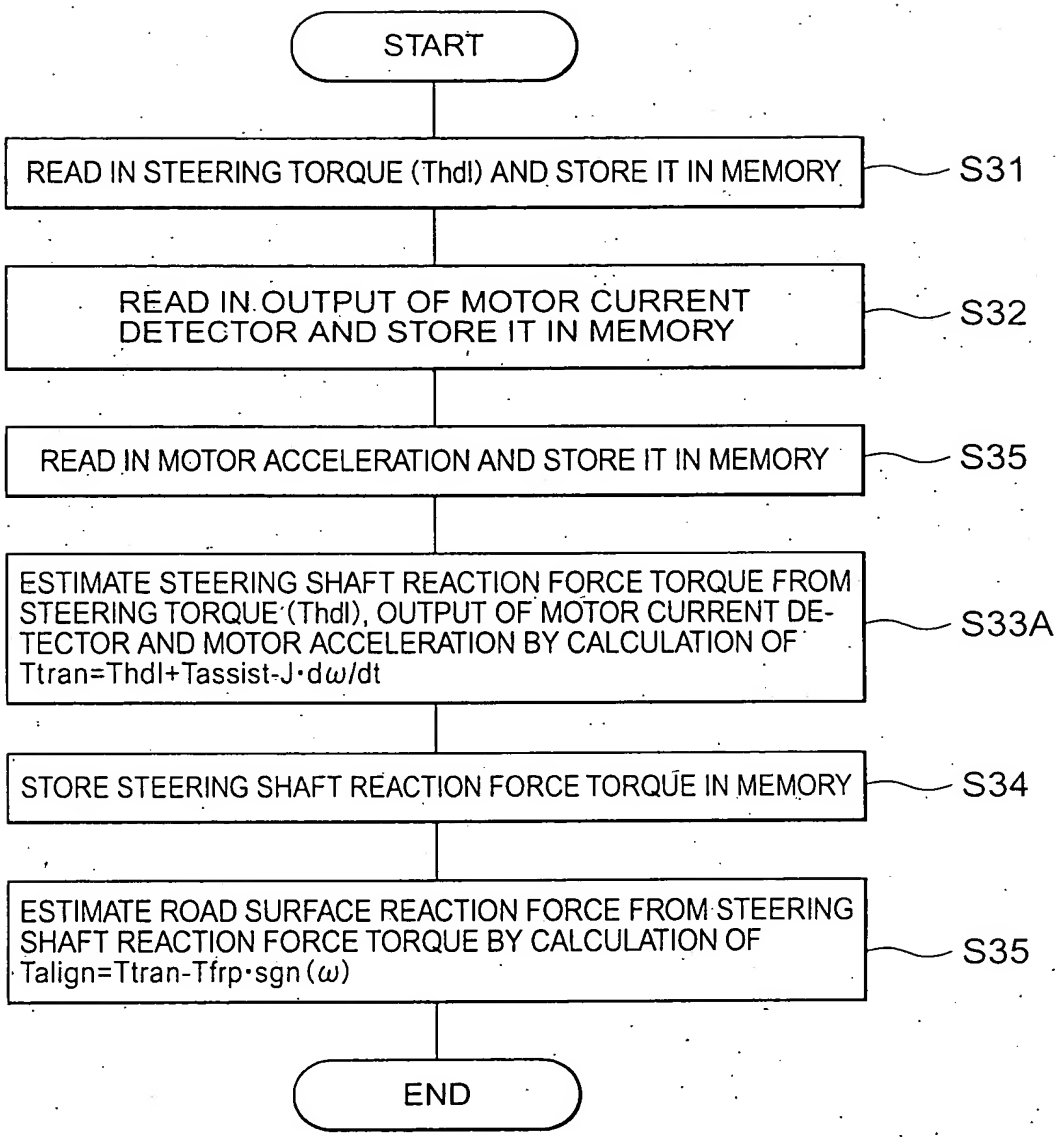
START
READ IN STEERING TORQUE (Thdl) AND STORE IT IN MEMORY
S31
READ IN OUTPUT OF MOTOR CURRENT DETECTOR AND STORE IT IN MEMORY
S32
READ IN MOTOR ACCELERATION AND STORE IT IN MEMORY
S35
ESTIMATE STEERING SHAFT REACTION FORCE TORQUE FROM STEERING TORQUE (Thdl), OUTPUT OF MOTOR CURRENT DETECTOR AND MOTOR ACCELERATION BY CALCULATION OF Ttran=Thdl+Tassist-J·dω/dt
S33A
STORE STEERING SHAFT REACTION FORCE TORQUE IN MEMORY
S34
ESTIMATE ROAD SURFACE REACTION FORCE FROM STEERING SHAFT REACTION FORCE TORQUE BY CALCULATION OF Talign=Ttran-Tfrp·sgn(ω)
S35
END

FIG. 24

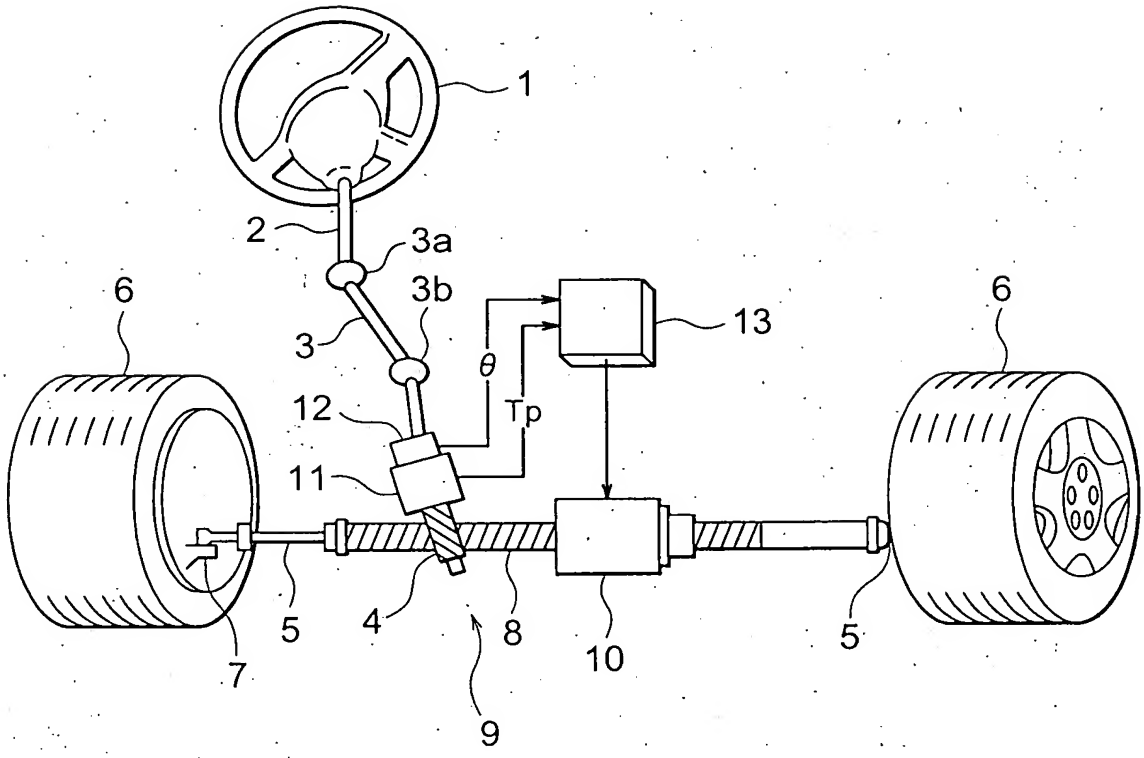
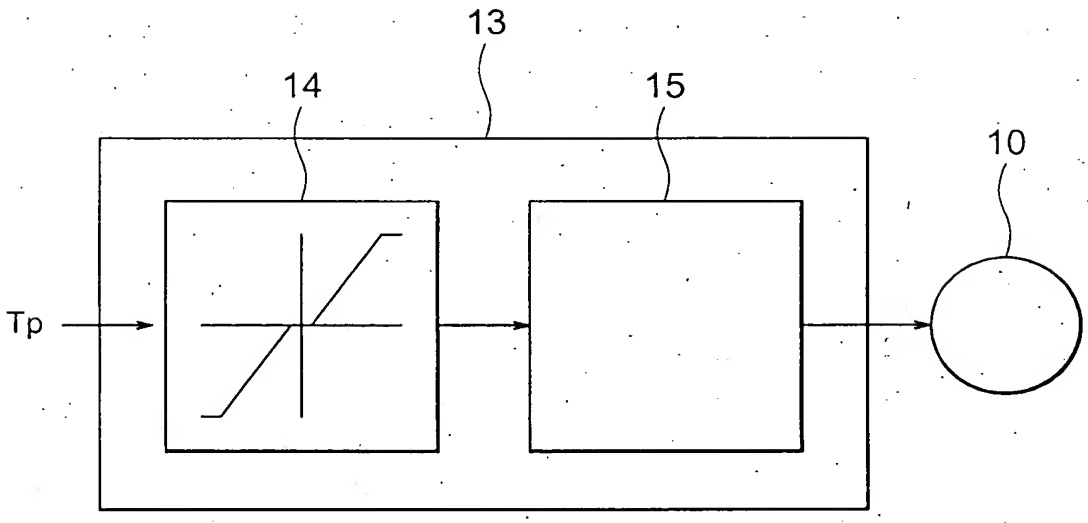
FIG. 25